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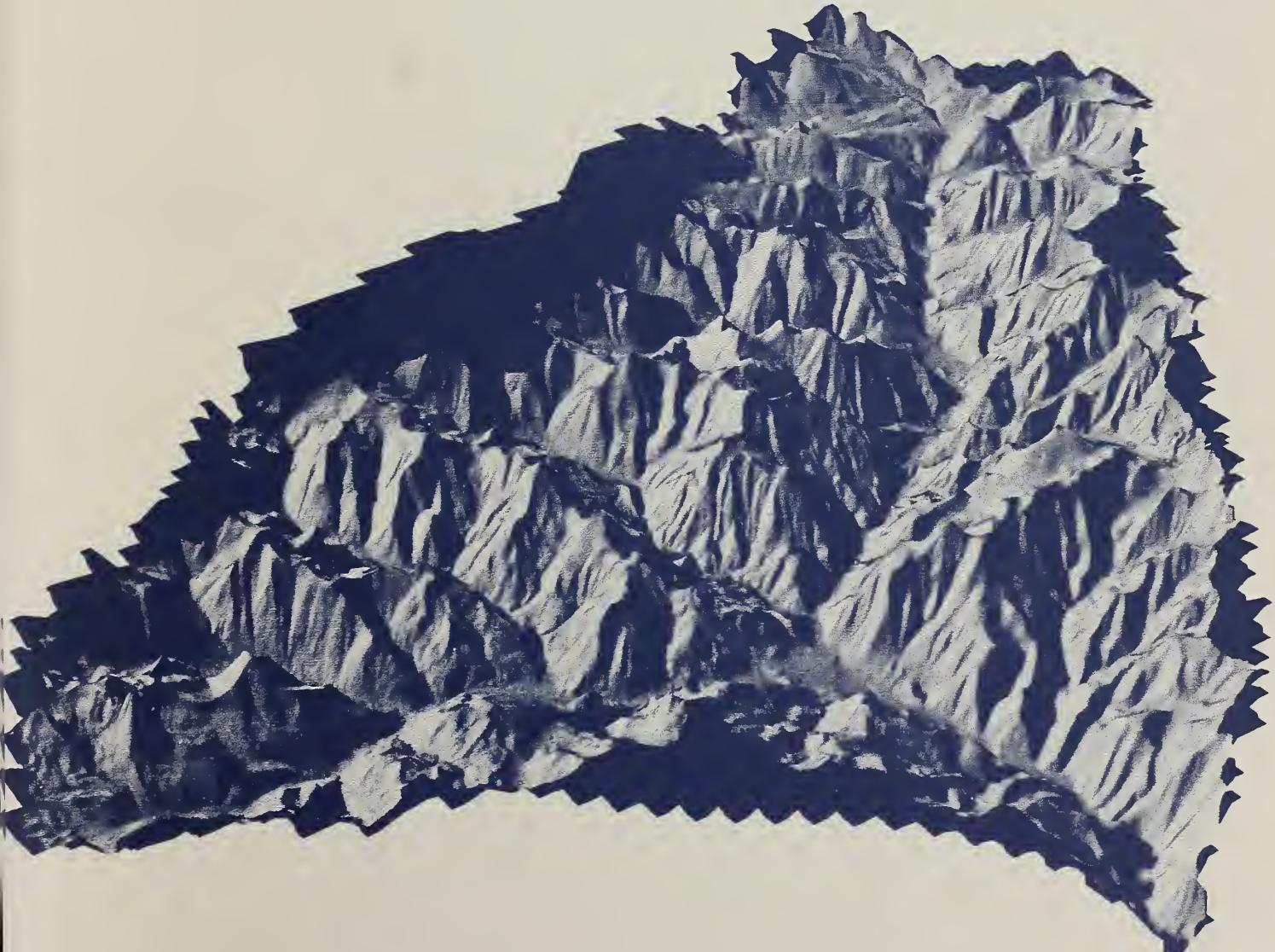
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Spatially Linking Basinwide Stream Inventories to Arcs Representing Streams in a Geographic Information System

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Research Summary

The R1/R4 [Northern Region/Intermountain Region] Fish and Fish Habitat Standard Inventory Procedures (Overton and others 1997) were used to classify and quantify salmonid stream habitat and determine salmonid distribution in the Yankee Fork watershed in central Idaho. Methods were developed to generate a spatial coverage of fish distribution and stream habitat conditions in a Geographic Information System (GIS). Using a spatially oriented fisheries database in concert with other GIS layers (for example, roads, grazing allotments, erosion hazards, vegetation types) provides the fisheries manager the analytical capabilities essential for conducting watershed analysis and ecosystem management. This paper outlines procedures to create a fishery GIS database using basinwide inventories and provides examples of the utility of a GIS in fisheries resource management.

Acknowledgments

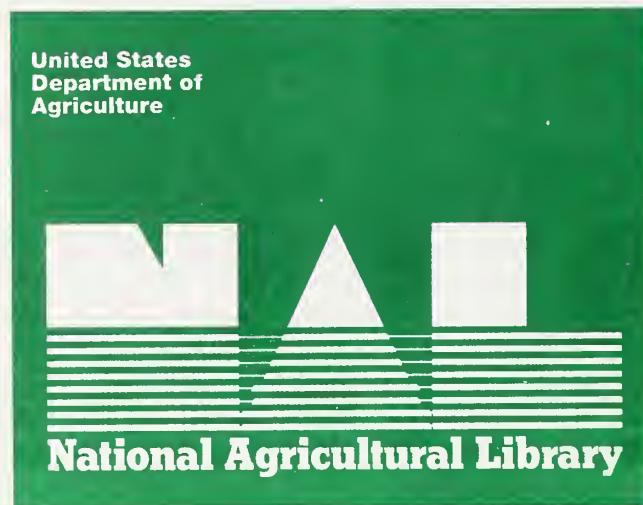
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Introduction

Basinwide stream habitat inventories completed in the Yankee Fork watershed were linked to arcs in a Geographic Information System (GIS) using *Dynamic Segmentation* tools in ARC/INFO® (ESRI 1995). With a spatially located stream habitat data set, it is possible to analyze stream habitat conditions relative to other features and processes represented in a GIS (for example, geology, vegetation, and roads) (Martischang 1993). Watershed analyses, biological evaluations, and management decisions can be strengthened and made more scientifically defensible with the added power of a spatial resource analysis. Besides its analytical potential, a GIS provides enormous organizational and information-sharing capabilities.

This paper details procedures used to link the R1/R4 Fish Habitat Inventory data sets and other basinwide stream surveys to digitized arcs representing streams in a GIS to permit query and spatial display of fish habitat conditions. A secondary objective was to generate and acquire other thematic layers across a sample watershed to build a comprehensive, spatially oriented resource information database. These additional spatial data layers included transportation, hydrography, grazing allotments, and mining activities. Additional watershedwide spatial data layers were created from cartographic feature files, digital elevational models (DEM), and manual digitizing. Data sources and conversion methods are documented. Finally, I give examples of some of the kinds of queries and spatial displays that can be performed using GIS resource information databases.

Study Area

Stream inventory data from the Yankee Fork watershed were used to demonstrate the application of dynamic segmentation tools to spatially link basinwide surveys to arcs in a GIS. The Yankee Fork watershed is located in central Idaho in the upper Salmon River basin (fig. 1). Its watershed area is approximately 49,202 ha (121,579 acres) in size and is entirely within the Challis National Forest (USDA 1995). The Yankee Fork drains approximately 359.8 km (223.6 miles) of perennial stream from its headwaters to the confluence with the Salmon River. An additional 468.8 km (291.3 miles) of seasonally intermittent tributaries can be found within the drainage. Elevations range from 1,900 m (6,200 ft) above sea level at its Salmon River confluence to more than 3,050 m (10,000 ft) on several mountain peaks. The Yankee Fork receives approximately 76 cm (30 inches) of precipitation annually (Davidson and Osbourne 1976). Mean annual air temperature averages 1 °C (33 °F) with extremes reaching 32 °C (90 °F) in the summer and

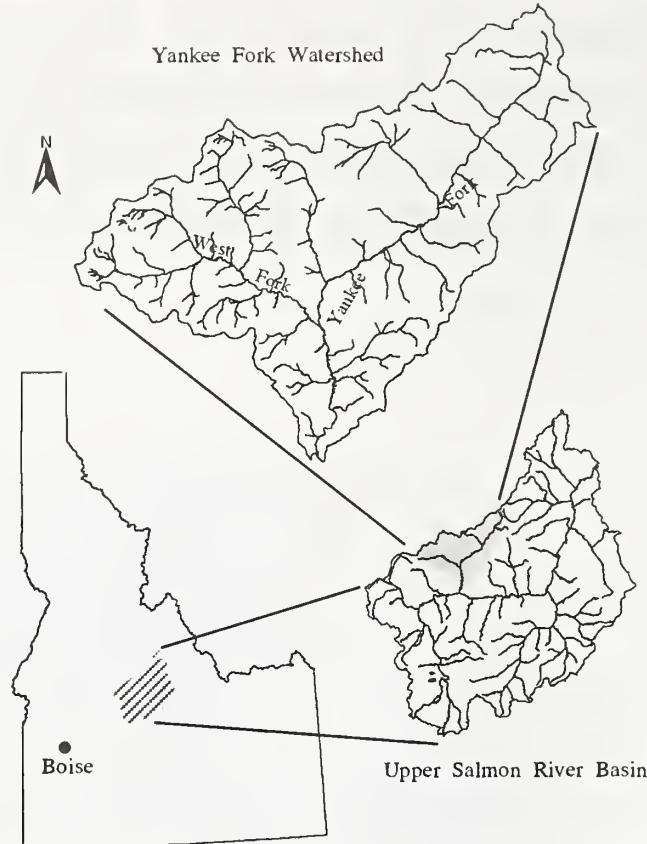


Figure 1—Location of the Yankee Fork watershed within the upper Salmon River basin.

–46 °C (–50 °F) in the winter. The Yankee Fork was formed primarily through extensive volcanic activity occurring 45 to 50 million years ago in central Idaho. Vegetative composition varies by elevation and aspect. The area is represented by montane and subalpine Rocky Mountain flora with some elements of intermountain flora near the eastern boundary (USDA 1995).

Methods

Twelve streams within the Yankee Fork watershed were surveyed in the summers of 1991 and 1994 using two types of basinwide stream habitat inventories: the Bonneville Power Administration Project Anadromous Fish Habitat Survey (BPA) (USDA 1991) and the R1/R4 [Northern Region/Intermountain Region] Fish and Fish Habitat Standard Inventory Procedures (R1/R4) (Overton and others 1997) (fig. 2). Stream inventory procedures were similar for most variables collected between the two types of inventory, but the software used to store the electronic data files was not. Both types of habitat inventory stratified streams into smaller sections termed reaches. The reach designation was the organizational unit used in both inventories to spatially locate habitat units in the GIS. Reaches were assigned channel typing codes determined by gradient and channel confinement quite similar to the Rosgen reach classification (Rosgen 1985).

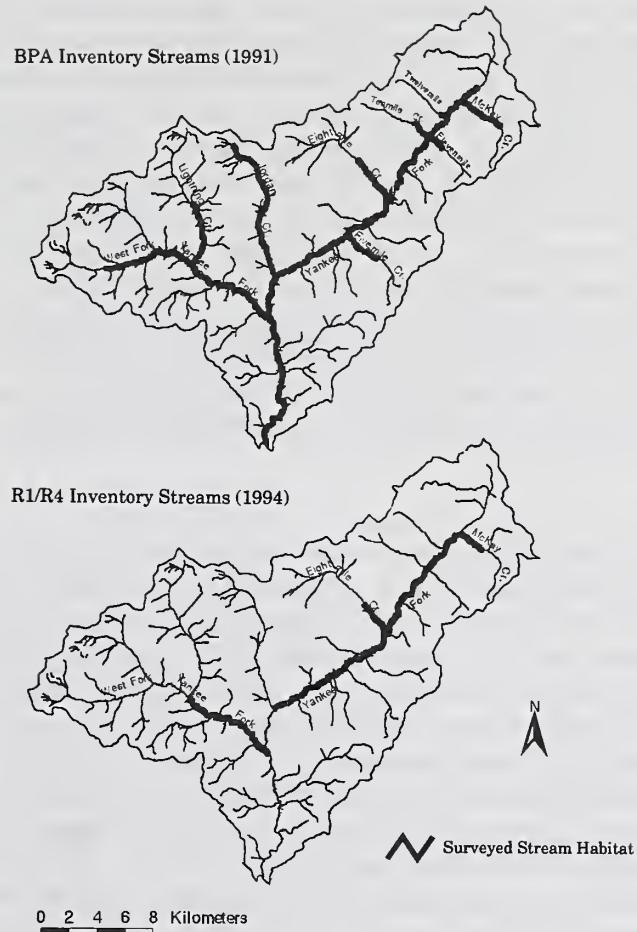


Figure 2—Stream surveys conducted in the Yankee Fork watershed, 1991 and 1994.

Within a reach, the stream section was further broken down into smaller geomorphic units called habitat types. Habitat types have been used by many researchers and managers as a way to characterize the habitat of different species, both terrestrial and aquatic (Bisson and others 1982; Hankin and Reeves 1988; Hawkins and others 1993). A hierarchical habitat type stratification scheme was used to further break down the habitat types into microhabitat units. The level of microhabitat unit stratification was different between survey types. The R1/R4 inventories were broken down into finer microhabitat units than the BPA inventories. In addition, the habitat unit codes used in the electronic databases were different between surveys. To simplify the database query process in ARC/INFO®, I recoded habitat types in the BPA inventory down to the smallest discernible habitat unit level using the R1/R4 codes. The assumptions, limitations, data file structures, definitions, and conversion procedures used are detailed by the type of habitat inventory conducted (see Basinwide Inventory Data Conversions).

Hydrography Base Layer

I used cartographic feature files available from the Region 4 Geometronics Service Center to create a hydrography GIS layer. A cartographic feature file

contains a multitude of point and linear features typically found on 1:24000 scale primary base series maps. In addition, each of these attributes is assigned a numeric code that enables a user to extract the feature or features of interest (for example, streams, roads). The cartographic feature file codes used to generate a streams component of a hydrography layer were 402, 403, 404, 405, 406, 407, 408, 409, 440, 441, 442, 443, 444, and 445. This query captured all perennial and intermittent waters for the analysis area. A list of cartographic feature file codes explaining attribution features can be obtained from the Geometronics Service Center. If I had included lakes in the hydrography layer, I would also have included the codes 321, 322, 323, 410, 411, 412, 413, 414, 415, 431, 432, 433, 434, 435, 436, 437, 438, and 439 to the aforementioned query. The hydrography base layer was used as a template for creating the stream habitat GIS layer.

Dynamic Segmentation

A group of reaches within a stream inventory is analogous to a collection of routes making up a route-system in a GIS. I chose to create routes at the reach level because of the influence of scale on the spatial alignment of habitat units. In experimenting with route attribution at the stream scale I determined, based on comparisons of dynamically segmented reach breaks and known reach breaks (for example, tributary junctions or bridge crossings), that creating routes at the stream level was seldom accurate. For streams with multiple basinwide surveys it is suggested that separate route-systems be created primarily to avoid confusion in database management, but also to differentiate between survey years and collection methods.

A route consisted of one or many whole arcs or pieces of arcs (sections). In instances where a stream survey reach ended or started within an arc segment (usually at Rosgen channel changes), that arc segment needed to be broken into smaller arc sections (as opposed to the manual splitting of the arc with a node and thus changing arc-node topology). Survey reach maps and descriptions were used to guide the creation of the route attribute tables to approximate the survey reach extent. A route-system was created for each stream within the Yankee Fork watershed that was surveyed. For streams that were inventoried using both methods, separate route-systems were created because the methods for reach delineation were different between surveys.

The first step in creating route-systems was to locate all reach breaks for a stream inventory on a primary base series map(s). Using field inventory maps or reach descriptions, reach boundaries were determined and marks were made on the map. Using ARCEDIT® (edit feature set for arcs), all arcs that were to be a part of the route-system were selected. Whole arcs that contained only a piece of the stream inventory were included; these arcs will be sectioned later. Once the arcs were selected, the MAKEROUTE command was used to create the route-system (syntax: MAKEROUTE <route name>). When naming route-systems, I considered nomenclature that gave the most information about the kind or type of information the route was providing. For stream inventories, consideration was given to the type of inventory (basinwide or monitoring), forest or district administering the stream, year of the inventory, and any other essential information necessary to differentiate between stream surveys.

Once the route-system was established, arc sections had to be segmented to create partial arcs. This needed to be done only when portions of a whole arc were surveyed. To edit the sections of the route-system, the edit feature had to be changed for sections (syntax: EDITFEATURE SECTION.<route name>). I selected the arc-section to segment and used the SPLIT command to break the section at the reach break. If the “upstream” portion of the two segmented sections was not needed in the route-system, I selected that section of the arc and deleted it.

When all sections were complete for the routes, it was time to make the routes for the stream reaches. I changed the edit feature to section (syntax: EDITFEATURE SECTION.<route name>), if it had not already been set. It was best to use SELECT PATH when selecting sections to create routes, because it ensured capturing all small sections from the start to finish of the reach that may be invisible to the naked eye when viewed at larger scales. If connectivity existed between the first section and the last section selected, then the selected area appeared highlighted on the screen. If connectivity did not exist, then there was a gap in the hydrography (possibly a lake or pond) and a SELECT BOX needed to be used instead. I used SELECT BOX to draw a box around the sections needed to create the route or reach, and I used ASELECT if the box did not capture all sections the first time. Once all sections were selected for a reach, I used the MAKEROUTE command again to assign the sections to a route within the current route-system (syntax: MAKEROUTE <route-system>). I continued this process until all reaches were assigned to individual routes within the route-system.

Once routes were created, a relate key item was established to provide a link to the inventory databases. This relate key item could be named anything, but was populated with the survey reach number. Using ARCEDIT®, I set the edit feature for routes (syntax: EDITFEATURE ROUTE.<route-system>). The ADDITEM command was used to add the relate key item field to the route-system. I called the relate key item SURV_REACH (syntax: ADDITEM SURV_REACH 5 5 I). I attributed the SURV_REACH variable with its assigned reach number by selecting the reach first and then using the CALCULATE command to populate the field with the appropriate reach number (syntax: CALCULATE SURV_REACH = 1). I recommend saving your work once all reaches have been assigned a survey reach number.

The final step in the creation of routes and route-systems was “trutting” the digitized arc segments with “on-the-ground” measures taken from the stream inventory. This was done to fit the GIS determined reach lengths to the actual survey reach lengths. To accomplish this, the total survey reach length was determined (this is often done outside the GIS, but can be accomplished within ARC/INFO® as well). I did a query on a PC that calculated the total survey reach length by summing all habitat unit lengths in a reach. The reach length value was then used with the REMEASURE command in ARCEDIT® to fit the spatial habitat data along the route by selecting the reach that needed its measurements updated and then typing REMEASURE 0 * (where * equals the total reach length). Each individual reach had a remeasure start value of “0” and end value equal to the total reach length. For example: when a reach was field measured to be 2,350.7 m long, the typed command was REMEASURE 0 2350.7. This was repeated for each survey reach until the entire route-system was updated. When completed, route measures equaled the field data lengths and the route-building process was complete.

Basinwide Inventory Data Conversions

I created stream habitat and fish survey data files in INFO format using the UNIX version of ARC/INFO® 7.03. Using survey reach maps and descriptions, I generated route attribute tables approximating the survey reach extent. Table 1 summarizes the sampled streams associated INFO file name (GIS Datafile), route attribute table (DynSeg), survey type (Survey), survey year (Year), and data records (Records).

Only main channel habitat units were spatially oriented in the GIS. Typically a cartographic feature file at a scale of 1:24000 scale does not have the resolution to capture channel separations. For that reason, side channel units were not spatially located in the GIS.

BPA Anadromous Fish Habitat Survey—The BPA Project Anadromous Fish Habitat Survey of the Yankee Fork watershed was conducted in the summer of 1991. Twelve streams were inventoried that year: Cabin Creek, Eightmile Creek, Elevenmile Creek, Fivemile Creek, Jordan Creek, Lightning Creek, McKay Creek, Ramey Creek, Tenmile Creek, Twelvemile Creek, West Fork of Yankee Fork, and Yankee Fork (fig. 3). All stream habitat data were originally stored electronically in EXCEL® v3.0 format (Microsoft 1993). This form of data storage was not suitable for use as a GIS database because text, reach level descriptors, and data summaries were contained within the datafile as well. I wrote macro utilities in EXCEL® that stripped out all of the stream habitat data and transferred them to a new database file that could be used by INFO in GIS. In all data files, missing or null data values were coded as negative (for example, -99.9). In cases where a habitat unit length was not reported, I assigned a value of one as the habitat length when calculating the TO field. Additionally, I wrote macro utilities in dBase IV® that calculated additional variables of interest not present in the raw data files (for example, habitat area, residual pool volume, and habitat volume).

Table 1—Stream habitat and snorkel sampling metadata.

| Stream name | GIS data file | DynSeg | Survey | Year | Type | Records |
|------------------|---------------|--------|--------|------|------|---------|
| Cabin Creek | CABIN_91.DAT | CAB_91 | BPA | 1991 | Hab | 6 |
| Eightmile Creek | EIGHT_91.DAT | EIG_91 | BPA | 1991 | Hab | 21 |
| Eightmile Creek | EIGHT_94.DAT | EIG_94 | R1R4 | 1994 | Hab | 205 |
| Eightmile Creek | EFISH_94.DAT | EFS_94 | R1R4 | 1994 | Fish | 49 |
| Elevenmile Creek | ELEVEN_91.DAT | ELV_91 | BPA | 1991 | Hab | 11 |
| Fivemile Creek | FIVE_91.DAT | FIV_91 | BPA | 1991 | Hab | 13 |
| Jordan Creek | JORDAN_91.DAT | JRD_91 | BPA | 1991 | Hab | 22 |
| Lightning Creek | LIGHT_91.DAT | LGT_91 | BPA | 1991 | Hab | 11 |
| McKay Creek | MCKAY_91.DAT | MKY_91 | BPA | 1991 | Hab | 8 |
| McKay Creek | MCKAY_94.DAT | MKY_94 | R1R4 | 1994 | Hab | 265 |
| Ramey Creek | RAMEY_91.DAT | RAM_91 | BPA | 1991 | Hab | 68 |
| Tenmile Creek | TEN_91.DAT | TEN_91 | BPA | 1991 | Hab | 2 |
| Twelvemile Creek | TWELVE_91.DAT | TWV_91 | BPA | 1991 | Hab | 1 |
| West Fork | WESTFK_91.DAT | WFK_91 | BPA | 1991 | Hab | 68 |
| West Fork | WESTFK_94.DAT | WFK_94 | R1R4 | 1994 | Hab | 217 |
| West Fork | WFISH_94.DAT | WFS_94 | R1R4 | 1994 | Fish | 72 |
| Yankee Fork | YANKEE_91.DAT | YFK_91 | BPA | 1991 | Hab | 127 |
| Yankee Fork | YANKEE_94.DAT | YFK_94 | R1R4 | 1994 | Hab | 865 |
| Yankee Fork | YFISH_94.DAT | YFS_94 | R1R4 | 1994 | Fish | 173 |



Figure 3—Streams surveyed using the BPA habitat inventory procedures (1991).

Each habitat unit in the database was assigned a FROM, TO, and MID positional length variable that was determined based on the habitat unit length and the distance of the individual habitat unit to the beginning of the reach. These attributes are what the GIS will use to properly place each habitat unit in a reach along the route-system. The FROM and TO variables inform the GIS where along the route the habitat unit begins and ends. The MID variable was used for spatial display purposes only. For example: the first habitat unit of Reach 1 is measured to be 15.5 m long. Its FROM attribute will be 0 (since it begins at the stream confluence), its TO attribute will be 15.5 ($0 + 15.5$), and its MID value will be 7.75 ($0 + (15.5/2)$). The second habitat unit of Reach 1 is measured to be 10.2 m long. Its FROM attribute will be 15.5 (the TO value from the previous habitat unit), its TO attribute will be 25.7 ($15.5 + 10.2$), and its MID value will be 20.6 ($15.5 + 10.2/2$). Figure 4 illustrates how habitat units can be addressed spatially relative their positions with the reach beginning.

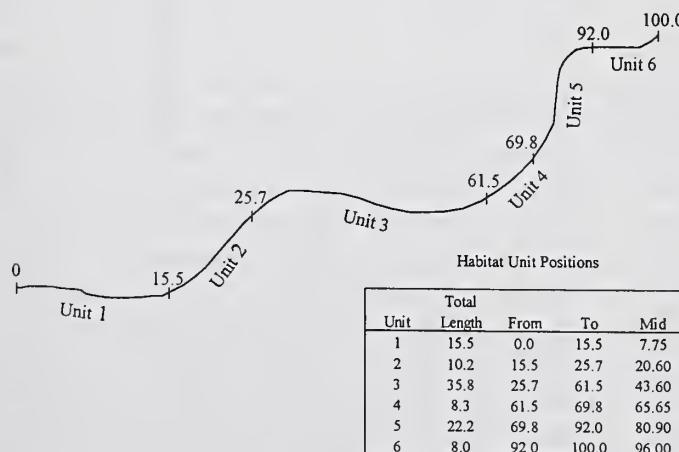


Figure 4—Habitat unit mapping with address locations along an arc in a route-system.

Once the data files had their FROM, TO, and MID attributes calculated, each stream habitat datafile was saved as a dBase® table (.dbf) (Borland 1993). The data files were transferred from the PC to a UNIX workstation using FTP protocol. The files were copied into the subdirectory where the stream habitat coverage was stored, to keep the locations of the files simple. I then used the ARC/INFO® command DBASEINFO to convert the file from a .dbf format to an INFO file format.

Field name definitions, field size, and field type were included to provide a user the ability to reference the data (table 2). A brief description of the attribute was also provided to further expand on the field name acronym. Definitions of the data type held in the field, in addition to sampling methodology used, can be found in the original contract specifications (USDA 1991).

Table 2—The 1991 BPA and 1994 R1/R4 stream habitat data file structure.

| Item name | Width | Output | Type | Decimals | Description |
|------------|-------|--------|------|----------|----------------------------------|
| STREAM | 30 | 30 | C | — | Stream name |
| STREAM_ID | 7 | 7 | C | — | Stream ID number |
| SURV_REACH | 5 | 5 | I | — | Reach number |
| REACH_TYPE | 1 | 1 | C | — | Gross rosgen |
| HAB_UNIT | 4 | 4 | I | — | Habitat unit number |
| UNIT_ID | 13 | 13 | C | — | Habitat unit ID number |
| CHAN_CODE | 1 | 1 | C | — | Channel type code |
| CHAN_TYPE | 4 | 4 | C | — | Channel type |
| SIDE_UNIT | 4 | 4 | I | — | Side channel number |
| MGMT | 6 | 6 | C | — | Management class |
| OBS_TYPE | 1 | 1 | C | — | Observation type |
| HAB_TYPE | 3 | 3 | C | — | Habitat type |
| HAB_GRP | 3 | 3 | C | — | Habitat group |
| HAB_CLS | 4 | 4 | C | — | Habitat class |
| START_LAT | 9 | 9 | C | — | Start latitude |
| START_LONG | 10 | 10 | C | — | Start longitude |
| POCKETS | 3 | 3 | I | — | Number of pocket pools |
| PKT_DEPTH | 5 | 5 | N | 2 | Pocket pool average depth |
| HAB_LENGTH | 7 | 7 | N | 1 | Habitat unit length |
| HAB_WIDTH | 4 | 4 | N | 1 | Habitat unit average width |
| HAB_AREA | 8 | 20 | F | 2 | Habitat unit surface area |
| HAB_VOL | 8 | 20 | F | 2 | Habitat unit volume |
| RESID_VOL | 8 | 20 | F | 2 | Residual pool volume |
| HAB_DEPTH | 5 | 5 | N | 2 | Habitat unit average depth |
| MAX_DEPTH | 5 | 5 | N | 2 | Habitat unit maximum depth |
| RESID_MXD | 8 | 20 | F | 2 | Residual pool maximum depth |
| WD_RATIO | 8 | 20 | F | 2 | Width/depth ratio |
| S_DEPTH_L | 5 | 5 | N | 2 | Shore depth left bank |
| S_DEPTH_R | 5 | 5 | N | 2 | Shore depth right bank |
| TAIL_DEPTH | 5 | 5 | N | 2 | Pool tail maximum depth |
| STP_NUM | 3 | 3 | N | 0 | Number of step pools |
| STP_AVG_DP | 5 | 5 | N | 2 | Step pool average depth |
| PCT_LGSUBS | 3 | 3 | I | — | Percent of large substrate cover |
| PCT_OVCOV | 3 | 3 | I | — | Percent of overhead cover |
| PCT_SUBCOV | 3 | 3 | I | — | Percent of submerged cover |
| PCT_UCUT | 3 | 3 | I | — | Percent of undercut bank cover |
| L_WT_SHAPE | 1 | 1 | C | — | Left wet bank shape |
| R_WT_SHAPE | 1 | 1 | C | — | Right wet bank shape |
| BFL_WIDTH | 6 | 6 | N | 1 | Bankfull width |

(con.)

Table 2 (Con.)

| Item name | Width | Output | Type | Decimals | Description |
|------------|-------|--------|------|----------|---|
| MX_BFL_DEP | 5 | 5 | N | 2 | Maximum bankfull depth |
| L_BFL_DEP | 5 | 5 | N | 2 | Left bankfull depth |
| R_BFL_DEP | 5 | 5 | N | 2 | Right bankfull depth |
| L_BF_SHAPE | 1 | 1 | C | — | Left bankfull shape |
| R_BF_SHAPE | 1 | 1 | C | — | Right bankfull shape |
| PCT_FINES | 3 | 3 | I | — | Percent substrate <0.2 cm |
| PCT_PGRAVL | 3 | 3 | I | — | Percent substrate 0.2-0.6 cm |
| PCT_GRAVEL | 3 | 3 | I | — | Percent substrate 0.6-7.5 cm |
| PCT_RUBBLE | 3 | 3 | I | — | Percent substrate 7.5-15 cm |
| PCT_COBBLE | 3 | 3 | I | — | Percent substrate 15-30 cm |
| PCT_BOLDER | 3 | 3 | I | — | Percent substrate >30 cm |
| PCT_BEDROK | 3 | 3 | I | — | Percent bedrock |
| PCT_SFINES | 3 | 3 | I | — | Percent of surface fines |
| LWD_SINGLE | 3 | 3 | I | — | Number of single pieces of LWD |
| LWD_WADS | 3 | 3 | I | — | Number of rootwads |
| LWD_AGREGS | 3 | 3 | I | — | Number of LWD aggregates |
| LEFT_LEN | 7 | 7 | N | 1 | Left bank total length |
| LEN_VGST_L | 7 | 7 | N | 1 | Length of vegetated-stable left bank |
| LEN_VGUS_L | 7 | 7 | N | 1 | Length of vegetated-unstable left bank |
| LEN_UVST_L | 7 | 7 | N | 1 | Length of unvegetated-stable left bank |
| LEN_UVUS_L | 7 | 7 | N | 1 | Length of unvegetated-unstable left bank |
| RITE_LEN | 7 | 7 | N | 1 | Right bank total length |
| LEN_VGST_R | 7 | 7 | N | 1 | Length of vegetated-stable right bank |
| LEN_VGUS_R | 7 | 7 | N | 1 | Length of vegetated-unstable right bank |
| LEN_UVST_R | 7 | 7 | N | 1 | Length of unvegetated-stable right bank |
| LEN_UVUS_R | 7 | 7 | N | 1 | Length of unvegetated-unstable right bank |
| LEN_UCUT_L | 7 | 7 | N | 1 | Length of undercut left bank |
| LEN_UCUT_R | 7 | 7 | N | 1 | Length of undercut right bank |
| LEN_GNTL_L | 7 | 7 | N | 1 | Length of gentle bank left bank |
| LEN_GNTL_R | 7 | 7 | N | 1 | Length of gentle bank right bank |
| LEN_STEP_L | 7 | 7 | N | 1 | Length of steep bank left bank |
| LEN_STEP_R | 7 | 7 | N | 1 | Length of steep bank right bank |
| H2O_TEMP | 5 | 5 | N | 1 | Water temperature |
| AIR_TEMP | 5 | 5 | N | 1 | Air temperature |
| COV_GRP | 6 | 6 | C | — | Reach cover group |
| COV_CLASS | 8 | 8 | C | — | Reach cover class |
| FROM | 9 | 9 | N | 1 | Habitat unit from position |
| TO | 9 | 9 | N | 1 | Habitat unit to position |
| MID | 9 | 9 | N | 1 | Habitat unit mid position |
| LAST_UNIT | 5 | 5 | I | — | Last unit in reach marker |

R1/R4 Fish Habitat Inventory—Select streams were resurveyed in the Yankee Fork watershed in 1994 using the R1/R4 Fish and Fish Habitat Standard Inventory Procedures (Overton and others 1997). The resurveys were in response to the need for additional stream habitat data for a biological assessment of the chinook salmon population. Methods used to collect the stream habitat data are similar between survey years, but the 1994 resurvey also collected fish population estimates. In 1994 four streams were sampled using the R1/R4 Fish habitat inventory procedures (fig. 5): Eightmile Creek, McKay Creek, West Fork of Yankee Fork, and Yankee Fork. The 1994 stream habitat data structure was the same as the BPA inventory (table 2). The fish snorkeling data structure is presented as table 3. Overton and others (1997) describe sampling methodologies and field name acronyms associated with the R1/R4 Fish and Fish Habitat Standard Inventory Procedures.



Figure 5—Streams surveyed using the R1/R4 habitat inventory procedures (1994).

Unlike the BPA inventory data files, the R1/R4 stream habitat data were stored in a relational database system that could transfer to INFO format rather easily. This relational data base system, FBASE, is a companion software program to the R1/R4 Fish Habitat Inventory Procedures (Overton and others 1997). FBASE provides data entry screens, automated data storage and retrieval, and many summarization routines (Wollrab 1996). In addition, a dynamic segmentation module (DynSeg) has been developed in FBASE that calculates all FROM, TO, and MID values for habitat units. Once the stream inventory data were entered, corrected, and DynSeg run on the file, all that remained was to copy the data file to the UNIX workstation (using FTP) and execute the DBASEINFO command from the ARC® prompt.

Additional Spatial Resource Layers

Elevation, Slope, and Aspect—Digital elevation models (DEM) were obtained from Region 4 Geometronics Service Center for the Yankee Fork watershed. These 7.5 minute grids are in raster format and have a resolution of 30 m. Once the DEMs were appended to form a single grid, I used the hydrologic modeling tools in the GRID® module of ARC/INFO® to create a “depressionless” DEM (ESRI 1995). FLOWDIRECTION and FLOW-ACCUMULATION commands were run on the resultant elevation grid to generate additional grids used to derive stream networks and watershed areas in raster format. The stream network grid was made using the GRID® SETNULL function where:

```
<stm_net> = SETNULL (<flow_accumulation grid> gt 100, 1)
```

Using this raster representation of stream networks from the elevation grid, I was able to visually identify the lowest point along the stream network in the Yankee Fork watershed. I used the GRID® SELECTPOINT function to select a point from the stream network grid that represented the “pour point” in the watershed. The Yankee Fork watershed was then delineated

Table 3—The 1994 R1/R4 fish inventory data file structure.

| Item name | Width | Output | Type | Decimals | Description |
|------------|-------|--------|------|----------|------------------------------------|
| STREAM | 30 | 30 | C | — | Stream name |
| STREAM_ID | 7 | 7 | C | — | Stream ID number |
| SURV_REACH | 5 | 5 | I | — | Reach number |
| REACH_TYPE | 1 | 1 | C | — | Gross rosgen |
| HAB_UNIT | 4 | 4 | I | — | Habitat unit number |
| UNIT_ID | 13 | 13 | C | — | Habitat unit ID number |
| CHAN_CODE | 1 | 1 | C | — | Channel type code |
| CHAN_TYPE | 4 | 4 | C | — | Channel type |
| SIDE_UNIT | 4 | 4 | I | — | Side channel number |
| HAB_TYPE | 3 | 3 | C | — | Habitat type |
| NUM_DIVERS | 8 | 3 | F | — | Number of divers |
| DIVER1 | 20 | 20 | C | — | Diver 1 name |
| DIVER2 | 20 | 20 | C | — | Diver 2 name |
| DIVE_DATE | 8 | 10 | D | — | Dive date |
| DIVE_TIME | 5 | 5 | C | — | Dive time |
| DIVE_WTEMP | 8 | 7 | F | 1 | Water temperature |
| DIVE_ATEMP | 8 | 7 | F | 1 | Air temperature |
| DIV_LENGTH | 8 | 9 | F | 1 | Habitat unit length |
| DIV_WIDTH | 8 | 6 | F | 1 | Habitat unit average width |
| DIV_DEPTH | 8 | 8 | F | 2 | Habitat unit average depth |
| DIV_MAX_DP | 8 | 8 | F | 2 | Habitat unit maximum depth |
| PCT_UC | 8 | 4 | F | 0 | Percent of undercut bank cover |
| PCT_OC | 8 | 4 | F | 0 | Percent of overhead cover |
| PCT_SC | 8 | 4 | F | 0 | Percent of submerged cover |
| PCT_LS | 8 | 4 | F | 0 | Percent of large substrate cover |
| CHIN_0 | 8 | 4 | F | 0 | Chinook age class 0 |
| CHIN_1 | 8 | 4 | F | 0 | Chinook age class 1 |
| ST_1 | 8 | 4 | F | 0 | Steelhead age class 1 |
| ST_2 | 8 | 4 | F | 0 | Steelhead age class 2 |
| ST_3 | 8 | 4 | F | 0 | Steelhead age class 3 |
| RB | 8 | 4 | F | 0 | Resident rainbow trout |
| CT_100 | 8 | 4 | F | 0 | Cutthroat trout <100 mm |
| CT_100_200 | 8 | 4 | F | 0 | Cutthroat trout 100-200 mm |
| CT_200_300 | 8 | 4 | F | 0 | Cutthroat trout 200-300 mm |
| CT_300 | 8 | 4 | F | 0 | Cutthroat trout >300 mm |
| BT_100 | 8 | 4 | F | 0 | Bull trout <100 mm |
| BT_100_200 | 8 | 4 | F | 0 | Bull trout 100-200 mm |
| BT_200_300 | 8 | 4 | F | 0 | Bull trout 200-300 mm |
| BT_300_400 | 8 | 4 | F | 0 | Bull trout 300-400 mm |
| BT_400_500 | 8 | 4 | F | 0 | Bull trout 400-500 mm |
| BT_500 | 8 | 4 | F | 0 | Bull trout >500 mm |
| YOY | 1 | 1 | C | — | Young of the year presence/absence |
| BK_100 | 8 | 4 | F | 0 | Brook trout <100 mm |
| BK_100_200 | 8 | 4 | F | 0 | Brook trout 100-200 mm |
| BK_200_300 | 8 | 4 | F | 0 | Brook trout 200-300 mm |
| BK_300 | 8 | 4 | F | 0 | Brook trout >300 mm |
| FROM | 9 | 9 | N | 1 | Habitat unit from position |
| TO | 9 | 9 | N | 1 | Habitat unit to position |
| MID | 9 | 9 | N | 1 | Habitat unit mid position |
| LAST_UNIT | 5 | 5 | I | — | Last unit in reach marker |

using this selected “pour point” as an input grid for the GRID® WATERSHED command:

`<watershed grid> = WATERSHED (<flow direction grid>, <pour point grid>)`

Using the newly created watershed boundary grid, I was able to generate slope and aspect grids that only covered the area within the Yankee Fork watershed (figs. 6 to 8). Slope and aspect were generated using the CURVATURE function in GRID®. Finally I converted the watershed grid

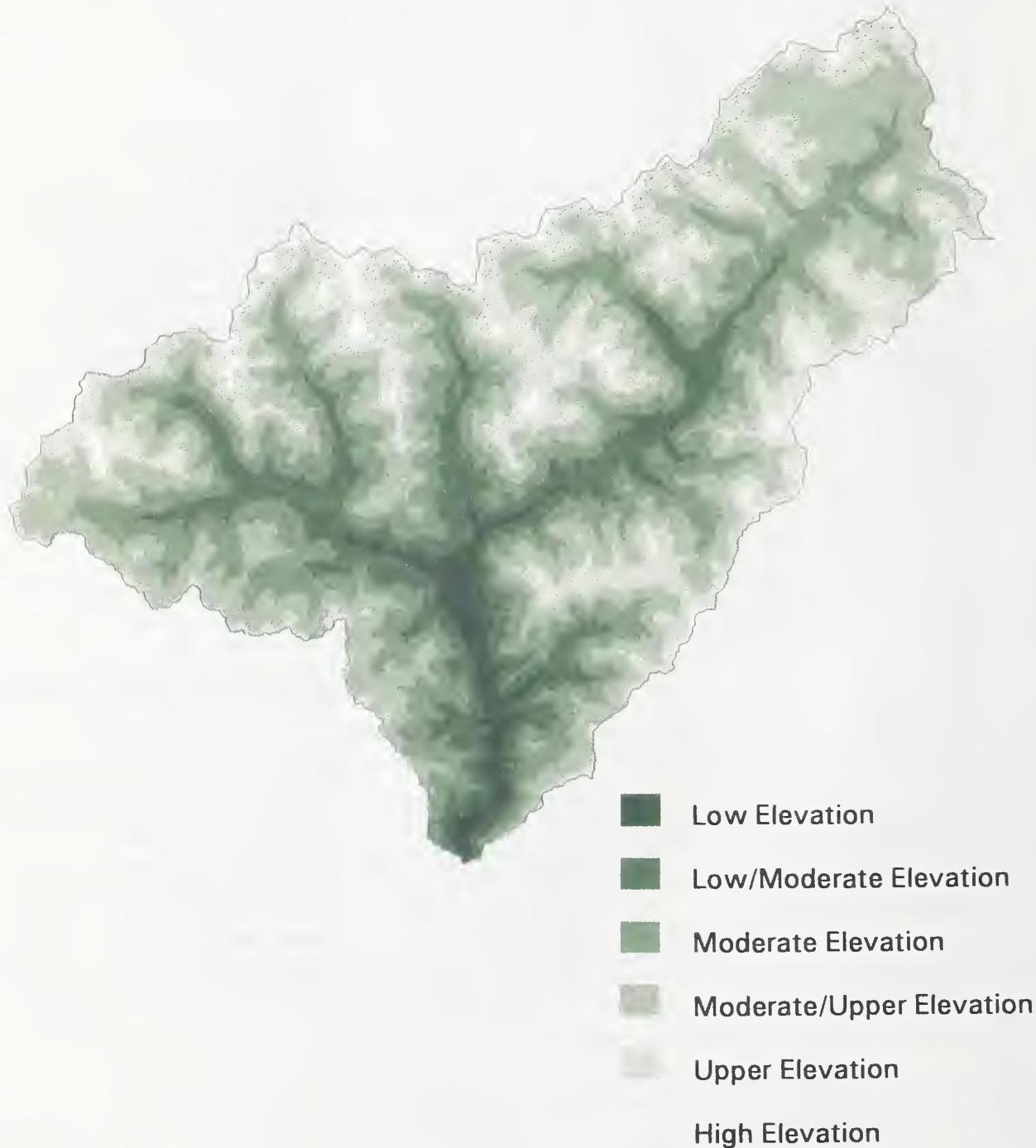


Figure 6—Yankee Fork elevation ranges.

into a polygon coverage for use with other vector data sets (primarily as a visual aid and clipping coverage).

Transportation—I used cartographic feature files to generate a base layer for transportation systems within the Yankee Fork watershed (fig. 9). I selected all arcs from the cartographic feature files that were designated as roads. The road selection criteria were obtained from macros received from Region 4 Geometronics Service Center that I slightly modified to meet the data needs. A list of the cartographic feature file codes used in the selection query were:

88-106, 108-116, 512-519, 528-529, 533-534, 750-753.

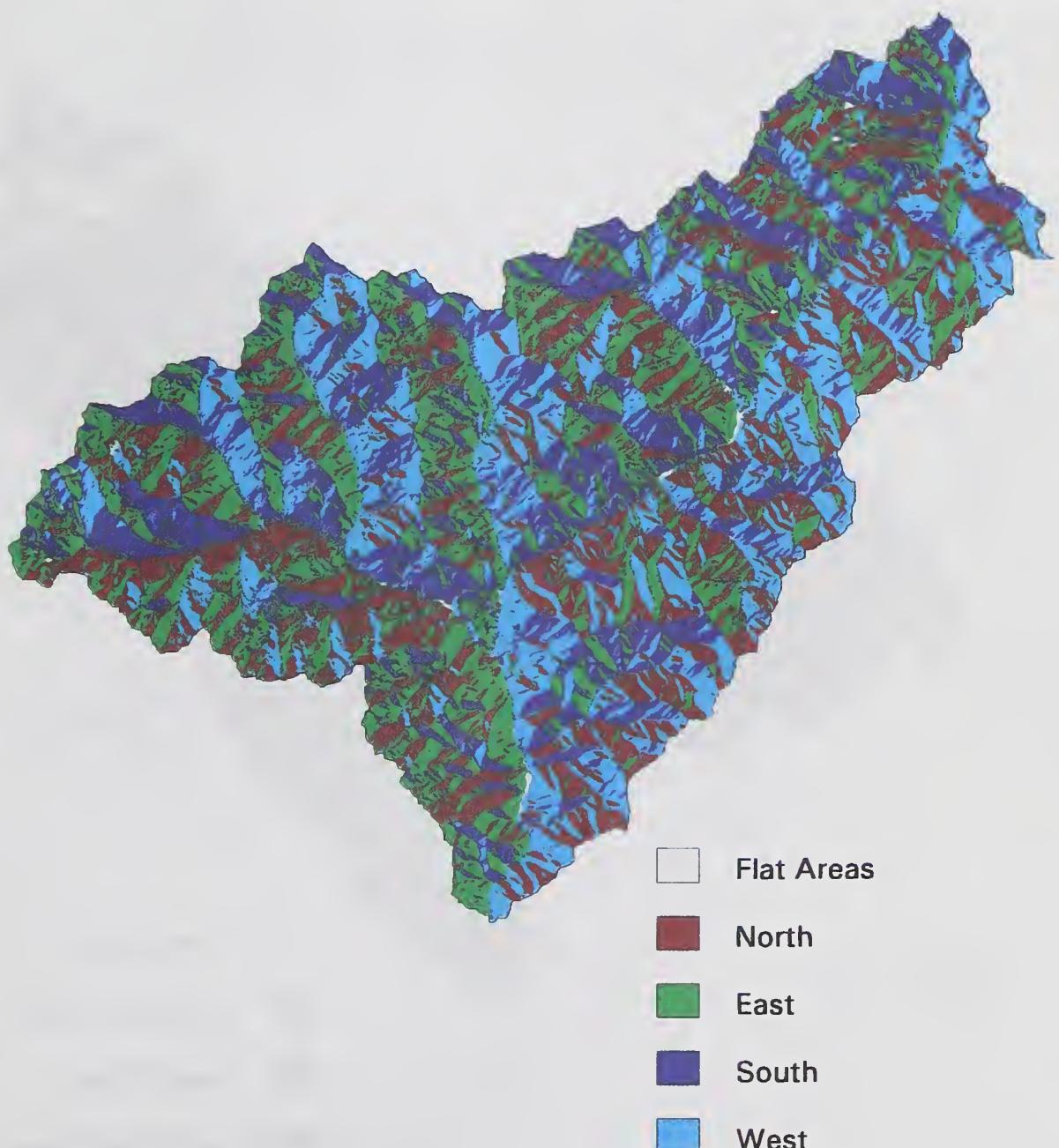


Figure 7—Yankee Fork aspect classification.

The transportation coverage was then clipped with the Yankee Fork watershed boundary to create a new layer that dealt only with the roads within the Yankee Fork watershed. Additional transportation series maps were obtained from the Challis National Forest that showed road location, road number, and maintenance schedule. Any additional roads not present in the first layer were added to the system by hand digitizing. The attributes for road number and maintenance schedule were added to the GIS database by visually selecting arcs and assigning the appropriate attribute value.

Grazing Allotments—The Yankee Fork contains a portion of the Garden Creek Cattle and Horse Allotment in the upper areas of the watershed (fig. 10). The boundary for this portion of the allotment was generated using the WATERSHED function in GRID®. A cattle guard located along USFS

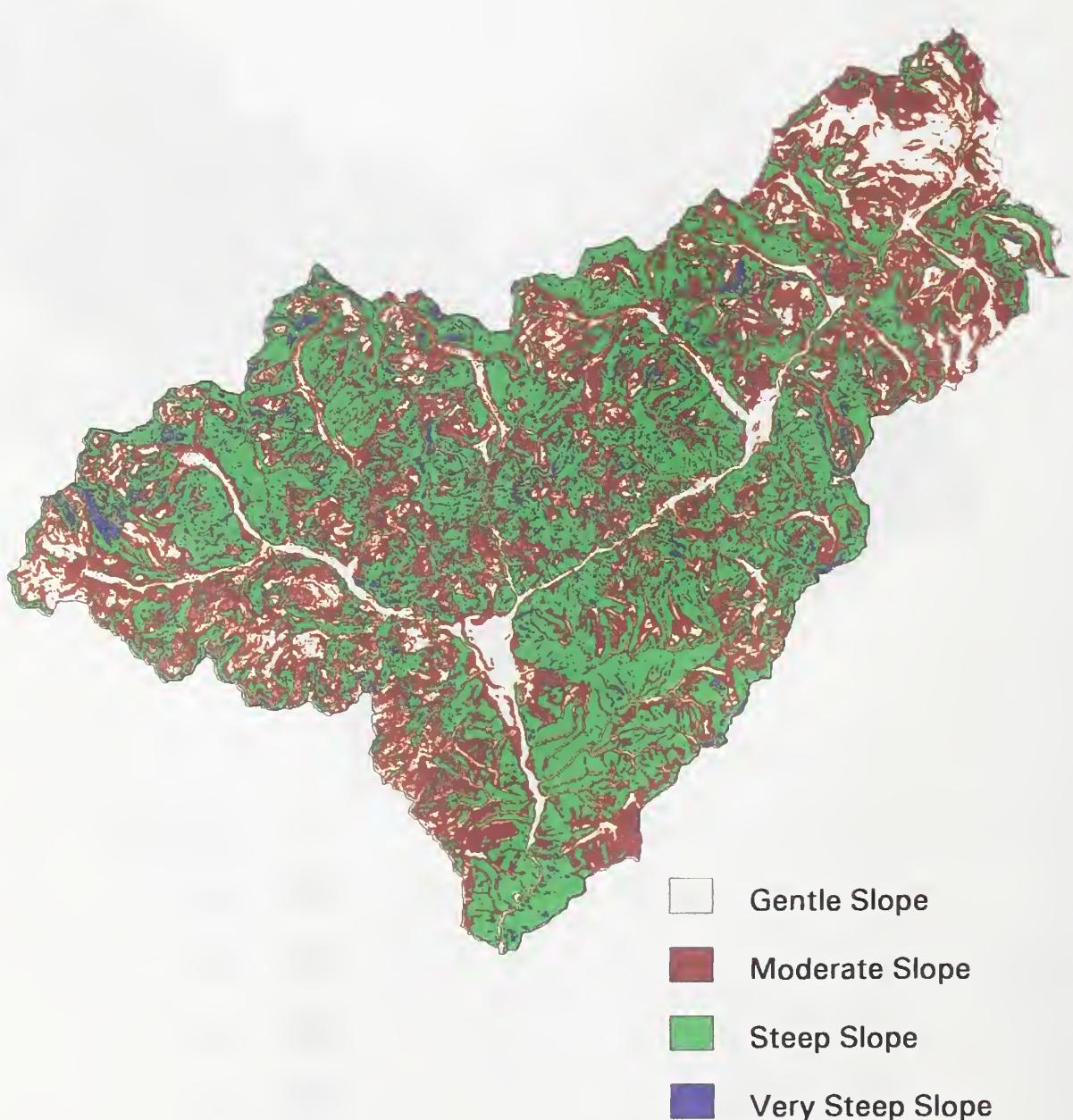


Figure 8—Yankee Fork slope delineation.

Road 070 served as an approximation for the lower "pour point" for this portion of the allotment. Using the GRID® SELECT function to estimate the cattle guard location, the WATERSHED function was run to create a grid of the allotment area. I then converted the allotment grid into vector format using the GRIDPOLY command in GRID®.

Vegetation and Timber Harvest—I obtained maps of the timber harvest units in the Yankee Fork watershed from the Challis National Forest. These harvest units were hand digitized and attributed using ARC/INFO®. Vegetation types were digitally scanned from maps provided by the Yankee Fork Ranger District. Attributes were entered into a database that was then joined to the vegetation polygons. The original data were interpreted from aerial photographs taken in 1963.

Mining Activities—I obtained maps of the mining activities in the Yankee Fork watershed from the Challis National Forest. These mining points and polygons were hand digitized and attributed using ARC/INFO®.

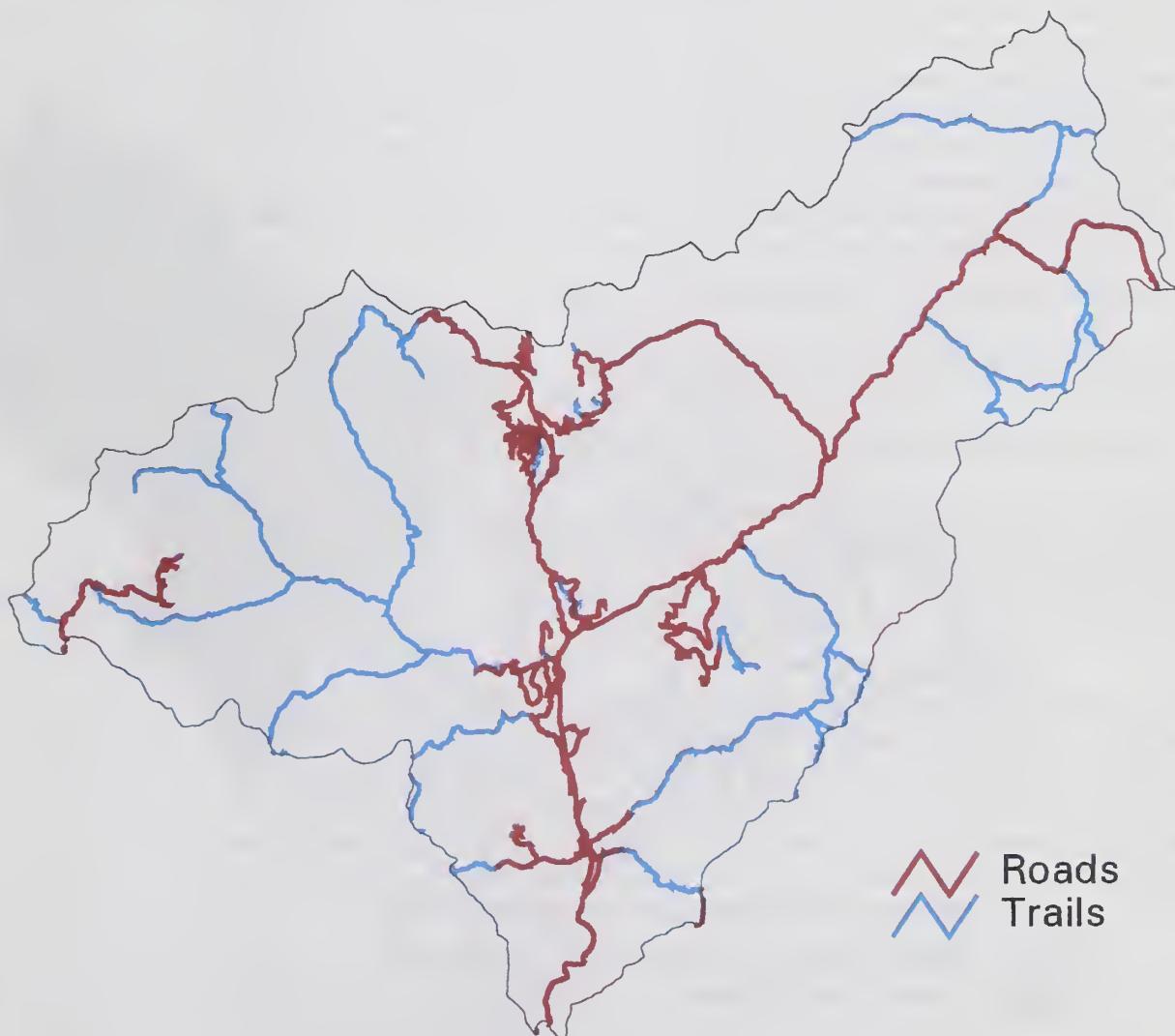


Figure 9—Yankee Fork transportation systems.

Once the route-systems and inventory database were in GIS, all that remained was to query the data set. Three steps were required to generate spatial queries of a dynamically segmented data set: (1) establish the relate between routes and the data tables, (2) query the stream inventory INFO database, and (3) display the results. The command used to establish the connection between the segmented routes and the associated stream habitat database was **EVENTSOURCE**. This command was specifically used to establish a database for event tables and the items in event tables, for use in subsequent event processing. The command usage was as follows:

```
EVENTSOURCE ADD <LINEAR | CONTINUOUS | POINT>  
<name> <data table>  
    INFO ordered <route_key> <event_key>
```

Based on the type of data in the event database, a choice of LINEAR, CONTINUOUS, or POINT data assignment must be made. I used the LINEAR option for database assignment; the use of this option required both



Figure 10—Yankee Fork grazing allotment and stream systems.

a FROM and TO measure in the event database. If the event database is CONTINUOUS, only a TO measure is necessary; the FROM is implied. This is also a valid option for basinwide surveys provided there are no missing habitat units. Finally, the POINT option can be used to locate the event using a measure along the route. I use the POINT option when I am interested in just the position of selected features (for example, habitat units).

Input for <name> is a user-defined name of the eventsource being created and <data table> is the name of the INFO stream habitat database of interest (refer to table 1, item GIS Data file). The <route_key> and <event_key> items are the variables identified in the route-system and event database that are used to relate the two tables. For the stream inventory databases, this relate item was the survey reach number. Suppose, for example, we were interested in the area of stream on the Yankee Fork in reach 16, and we wanted to spatially display all pool habitat locations in that area. And suppose further that we also wanted to show all areas in that reach where surface fines accumulations were greater than 20 percent and less than or equal to 20 percent. To accomplish this, we would have to first establish the relationship between the stream inventory databases and the Yankee Fork route-system (YANKEE94; refer to table 1, item GIS Data file). The first part of our query stated that we wanted to look at pool locations. For this example, we will show pools as points located along the stream section. The second part of our query stated our desire to show all surface fines accumulations surveyed along the reach. For this part of the example, we will show these areas as lines, using color to distinguish between the different query combinations. First we establish an eventsource for each of the two types of data (point and line) being displayed for the same section of stream on the Yankee Fork:

```
eventsources add point yank_pt yankee_94.dat info ordered surv_reach
surv_reach mid
```

```
eventsources add linear yank_lin yankee_94.dat info ordered surv_reach
surv_reach from to
```

Refer to the ARC/INFO® (ESRI 1995) user manual for further clarification on EVENTSOURCE syntax and input options.

Once the eventsource was established, we queried the inventory databases for attributes of interest. Tables 2 and 3 were used as reference to variable nomenclature when selecting variable names for query. The RESELECT command was used to retrieve information from the inventory databases:

```
RESELECT <data file> INFO <variable expression>
```

Inputs for <data file> was the name of the stream inventory INFO file (refer to table 1, item GIS Data file); <variable expression> syntax as well as additional RESELECT syntax and input options can be found in the ARC/INFO® user manual (ESRI 1995). For our example, the first query located all pools located in reach 16 on Yankee Fork, the second query showed all surface fines accumulations less than or equal to 20 percent, and the third query showed all surface fines accumulations greater than 20 percent:

```
reselect yankee_94.dat info surv_reach = 16 and hab_cls = 'SLOW'
reselect yankee_94.dat info surv_reach = 16 and pct_sfines ≤ 20
reselect yankee_94.dat info surv_reach = 16 and pct_sfines > 20
```

After the data attributes of interest were selected, commands dependent on the type of data (line or point) were used to display the results of the query by plotting them either to screen or paper. The choice of command was based

on the eventsource type used (linear, point, or continuous). For our example query, we had one point display (pools) and two linear events (less than or equal to 20 percent and more than 20 percent). We drew the linear outputs using the EVENTLINES command and points as symbols using the EVENTMARKERS command. Command syntax for each of the commands was as follows:

```
EVENTLINES <cover> <data table> <name> <color number>
EVENTMARKERS <cover> <data table> <name> <item> # <symbol number>
```

Refer to the ARC/INFO® user manual (ESRI 1995) for further clarification on EVENTLINES and EVENTMARKERS syntax and input options. The input for <cover> was the name of the hydrography coverage that had the route-systems created for the habitat inventories. The <data table> was the name of the dynamically segmented route, and <name> was the user-defined name of the eventsource. We drew the queried items from ARCPLOT® to get the output directed to the screen or to a plot file. It was easiest to use the Arc Macro Language of ARC/INFO® to create scripts that run programs that drew the queried output to screen or file. Remember that in ARC/INFO® when using a RESELECT command on a data file, the database query had to be cleared with a CLEARSELECT to requery the file for additional information; otherwise, subsequent queries were made only on the previously selected set. To properly draw something queried, the draw command **must** immediately follow the query command. The following commands illustrate the proper sequence of commands used to set up the relates, query the databases, and display output to the screen or a file:

```
eventsources add point yank_pt yankee_94.dat info ordered surv_reach
surv_reach mid
eventsources add linear yank_lin yankee_94.dat info ordered surv_reach
surv_reach from to
reselect yankee_94.dat info surv_reach = 16 and hab_cls = 'SLOW'
eventmarkers yfk_stm yankee94 yank_pt 1
clearselect
reselect yankee_94.dat info surv_reach = 16 and pct_sfines ≤ 20
eventlines yfk_stm yankee94 yank_lin 3
clearselect
reselect yankee_94.dat info surv_reach = 16 and pct_sfines > 20
eventlines yfk_stm yankee94 yank_lin 2
clearselect
```

The script above, in concert with additional map plotting commands, produced a display showing the spatial distribution of pool habitats in reach 16 of the Yankee Fork along with classified surface fines accumulations (fig. 11).

Discussion

Creating spatially oriented stream habitat databases from basinwide inventories using dynamic segmentation tools proved to be a suitable approach for locating habitat conditions in a GIS. The added power of a spatial fisheries analysis, in concert with other resource management GIS layers, can strengthen fisheries management decisions by revealing cause and effect relationships between activities and stream channel adjustments. Simple queries of stream habitat conditions and watershed activities may show

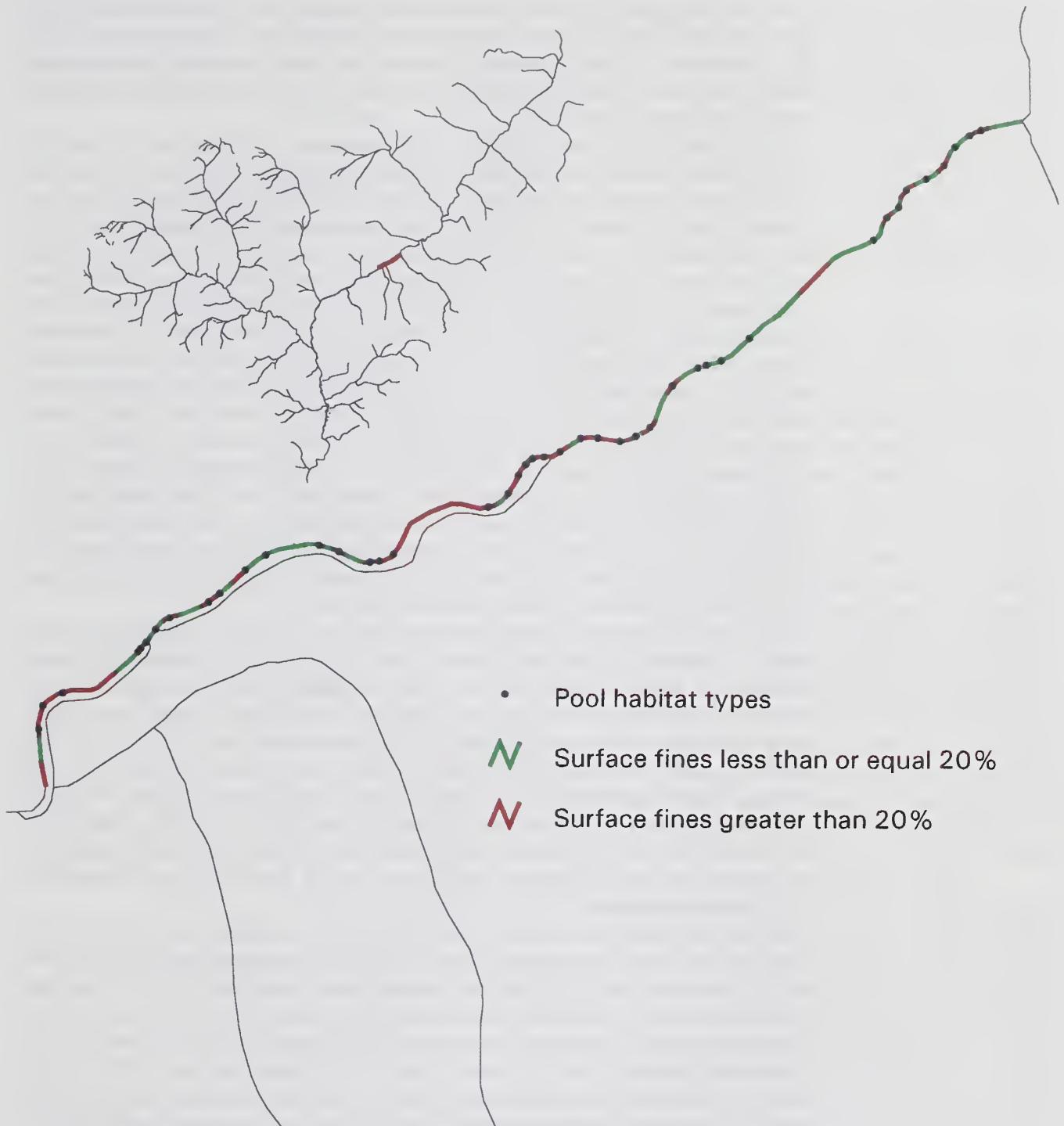


Figure 11—Distribution of pool habitats and surface fines in Reach 16, Yankee Fork.

visual associations that could alert resource managers to site-specific activities that may be damaging the aquatic environment. If nothing else, performing spatial habitat queries in concert with other resource management data layers may reveal intriguing spatial patterns that stimulate alternative analytical approaches.

The mapping of stream habitat conditions in a GIS can also be used to provide information for the development of aquatic monitoring programs. The Forest Service uses monitoring to collect information about a resource, to evaluate if the objectives or assumed results of a management plan have been realized. Some of the challenges in developing a sound monitoring program include the selection of representative variables, repeatable measures, sampling design, and cost. The selection of variables and how they are to be measured is dependent on the analytical scale and types of questions being asked. Which variables and how many are sampled are more statistically driven questions than they are spatial. Once these statistical analyses are addressed, then the GIS can be used to guide the selection of monitoring stations. Station selection can be driven by the presence or absence of a certain management activity, distance to the previous monitoring site, or the unique combinations of different landscape features. Combining spatial overlays of the landscape variables of interest in a GIS can focus the placement of monitoring sites to areas with the desired combination of watershed conditions. Additionally, a GIS can be used to assess distances and travel time between the monitoring sites.

Database queries for favorable stream habitat conditions, based on species-specific life stage habitat requirements as described in the scientific literature, can be used to identify and spatially display “critical” habitats. Current conservation theory describes the identification of “core areas” used in the development of conservation strategies for populations at risk of extinction (Rieman and McIntyre 1993; USDA 1996). Core areas must provide all critical habitat elements and should be selected from the best available habitat for the species of concern (Rieman and McIntyre 1993). Basinwide stream habitat inventories contained in a GIS provide the data and analytical tools that can efficiently define core areas based on species-specific habitat requirements.

What-if scenarios may be simulated using a spatially oriented stream habitat database. For example, if bank stability were increased by 5 percent, in which areas would effects be most notable and how much potential sedimentation might that reduce? Quantitative questions of how many and how much can be answered without a GIS through a simple query of the database; however, the full importance of the question may not be fully realized without the enhanced power of a spatial display. In our bank stability question, suppose we have limited funding for streambank rehabilitation projects. To narrow down the choice of the field, one might wonder what areas of habitat have the best chance for improvement? The manager could look at the deviation from the desired condition and determine that 50 to 75 percent deviation is poor, 25 to 50 good, and 10 to 25 percent excellent. A subsequent plot of the classes of bank stability deviation might lead the investigator to areas where fewer dollars could be spent on small fixes, and more dollars spent in areas where the need is greatest.

Complex and innovative GIS uses are now possible and are needed (Giles and Nielsen 1992). Landscapes are best modeled using raster, or cell based data where the analytical units are the same size dimensionally. Raster

data can be continuous, such as elevation or air temperature. Raster data can also be categorized or classified, like landform or soil type. The power in landscape modeling with raster data bases lies in the tools provided in ARC/INFO's® raster processing package, or GRID®. GRID® provides the GIS user the ability to add, subtract, multiply, clip, query, and statistically model relationships among many "grids," or individual landscape surface variables. In addition, GRID® has the ability to track movement from cell-to-cell; therein lies the potential to perform either surface or rudimentary ground-water modeling (ESRI 1995). Using universal soil-loss equations, soil types, road locations, and digital terrain models, it is possible to predict land and streambank erosion, and turbidity and sedimentation throughout a stream system (Giles and Nielsen 1992).

Many resource professionals will not have the skills to efficiently operate GIS software and manage complex databases on advanced computing systems. One method of bridging this gap between computer specialists and resource managers is through the development of customized graphical user interfaces. ARC/INFO® provides a built-in programming language called the Arc Macro Language to create menus, forms, access databases, and run routines for designing customized end-user applications. Arc Macro Language can be used by GIS specialists to create graphical user interface objects with which resource managers can access spatial databases and relate to attribute databases. "Point and click" query features would be used to identify the area of interest, data layers of choice, and query variables desired in assisting the manager in analyzing the resource condition. The query features would automatically assemble the required GIS coverages necessary for the analysis; the user would not have to have detailed programming GIS knowledge to do this. The only knowledge required by the end-user would be how to start the application and the variables used in the analysis. Additionally, models might be incorporated to the graphical user interface applications to ask the "what-if" questions in assessing multiple land use practices. Plotting functions could be programmed that write the information used to build the visual display to a file. The end-user would only need to specify the output device and page size for generation of a map.

Recently, ESRI® developed a product named Arcview 2.1 that is aimed at beginning GIS users. Arcview can work with spatial datasets, tables, charts, and images. It is relatively easy to load spatial datasets and the query interface provides the capability to selectively display attributes of interest. Because the software tries to minimize the GIS skills needed to operate the system, it has fewer advanced spatial analysis tools. Presently, the route-building functions of dynamic segmentation are not directly supported by Arcview. Perhaps as more people use dynamic segmentation, a case for advanced dynamic segmentation tools and their inclusion in subsequent Arcview versions will be made.

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Other publications about fish habitat and still available from the Intermountain Research Station:

R1/R4 (Northern Region/Intermountain Region) Fish Habitat Standard Inventory Procedures Handbook

by C. Kerry Overton, Sherry P. Wollrab, Bruce C. Roberts, and Michael A. Radko
General Technical Report INT-GTR-346 (February 1997)

User's Guide to Fish Habitat: Descriptions that Represent Natural Conditions in the Salmon River Basin, Idaho

by C. Kerry Overton, John D. McIntyre, Robyn Armstrong, Shari L. Whitwell, and Kelly A. Duncan
General Technical Report INT-GTR-322 (August 1995)

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Radko, Michael A. 1997. Spatially linking basinwide stream inventories to arcs representing streams in a Geographic Information System. Gen. Tech. Rep. INT-GTR-345. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 22 p.

Basinwide stream habitat inventories were linked to arcs representing streams in a Geographic Information System (GIS). The creation of a fish habitat GIS layer provides fisheries and land managers additional data that can be queried in relation to other landscape features and processes (for example, vegetation, roads, erosion) in a GIS for analytical or planning purposes. With the added power of a spatial analysis, fisheries management decisions can be further strengthened. Additionally, a GIS offers enormous organizational and information-sharing capabilities in a corporate database environment.

Keywords: streams, habitat inventories, GIS, ARC/INFO, dynamic segmentation, watershed, spatial analysis

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